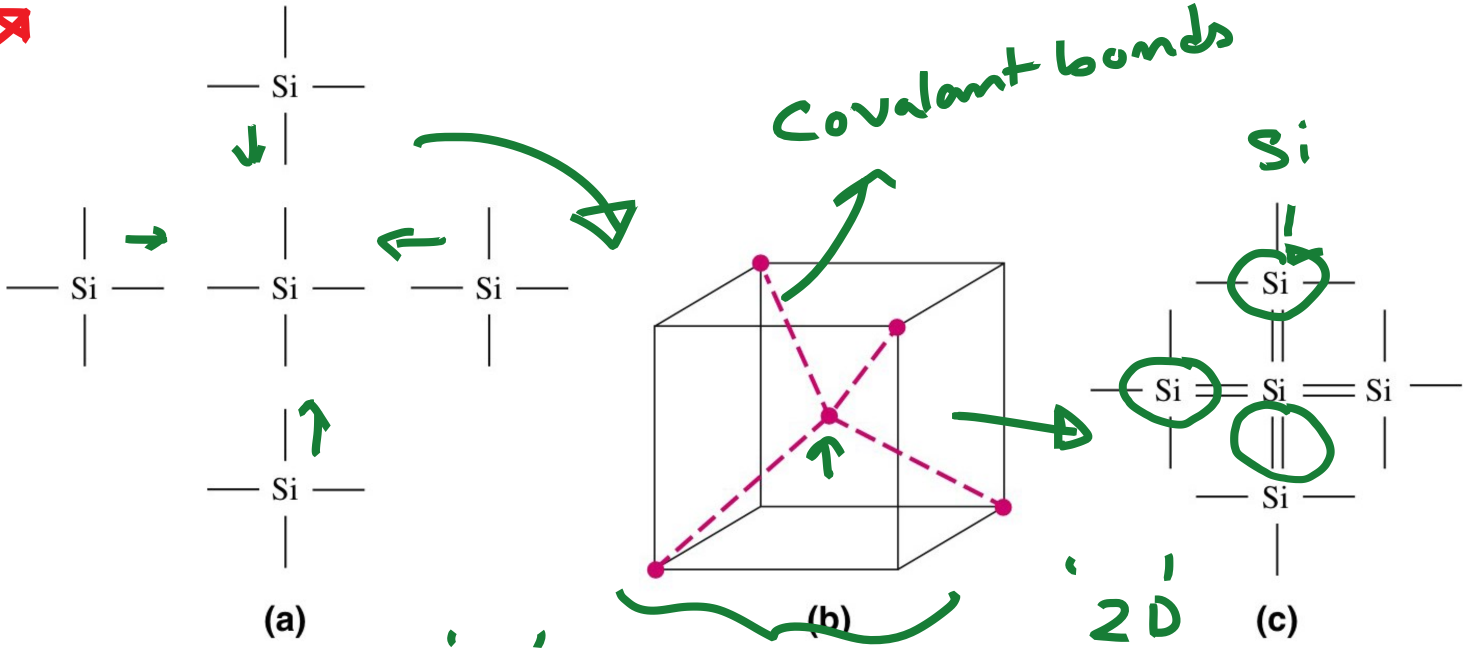
Semiconductor: Silicon

Group-IV

$Si\ (14) \Rightarrow 1s^2 2s^2 2p^6 \underbrace{3s^2 3p^2}$ 4 Valence electrons

$Ge\ (32) \Rightarrow \cdots 3d^{10} 4s^2 4p^2$

'Ge'

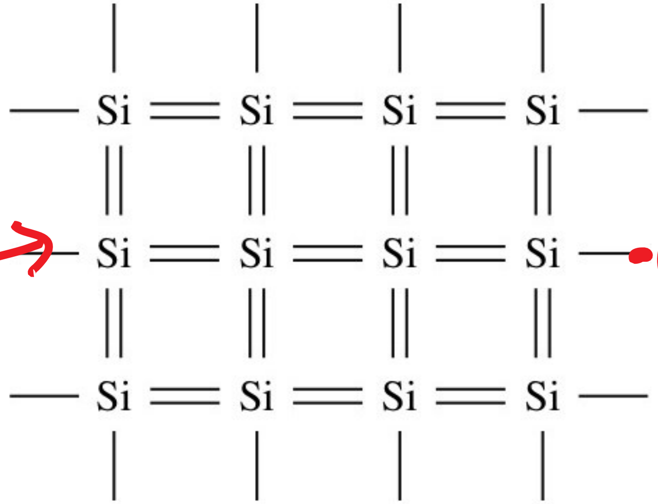


Covalent bonding of one Si atom with four other Si atoms to form tetrahedral unit cell.

Valence electrons available at edge of crystal to bond to additional Si atoms.

Source: Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill

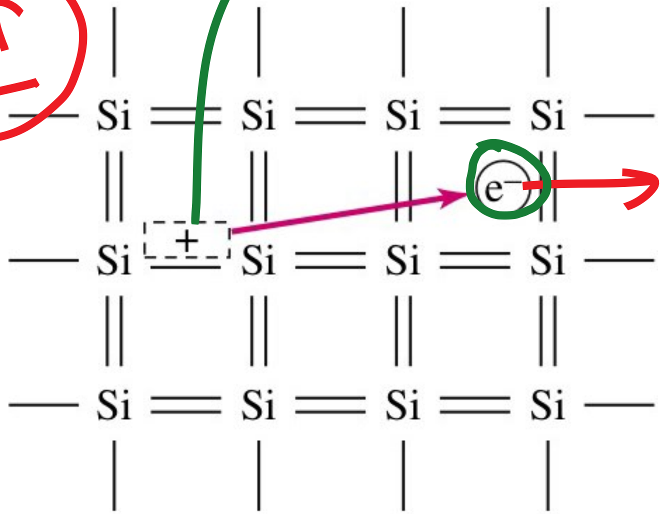
Silicon: Effect of Temperature



Temp↑

Temp↑

'hole' *



Current conduction

At 0 K, no bonds are broken.

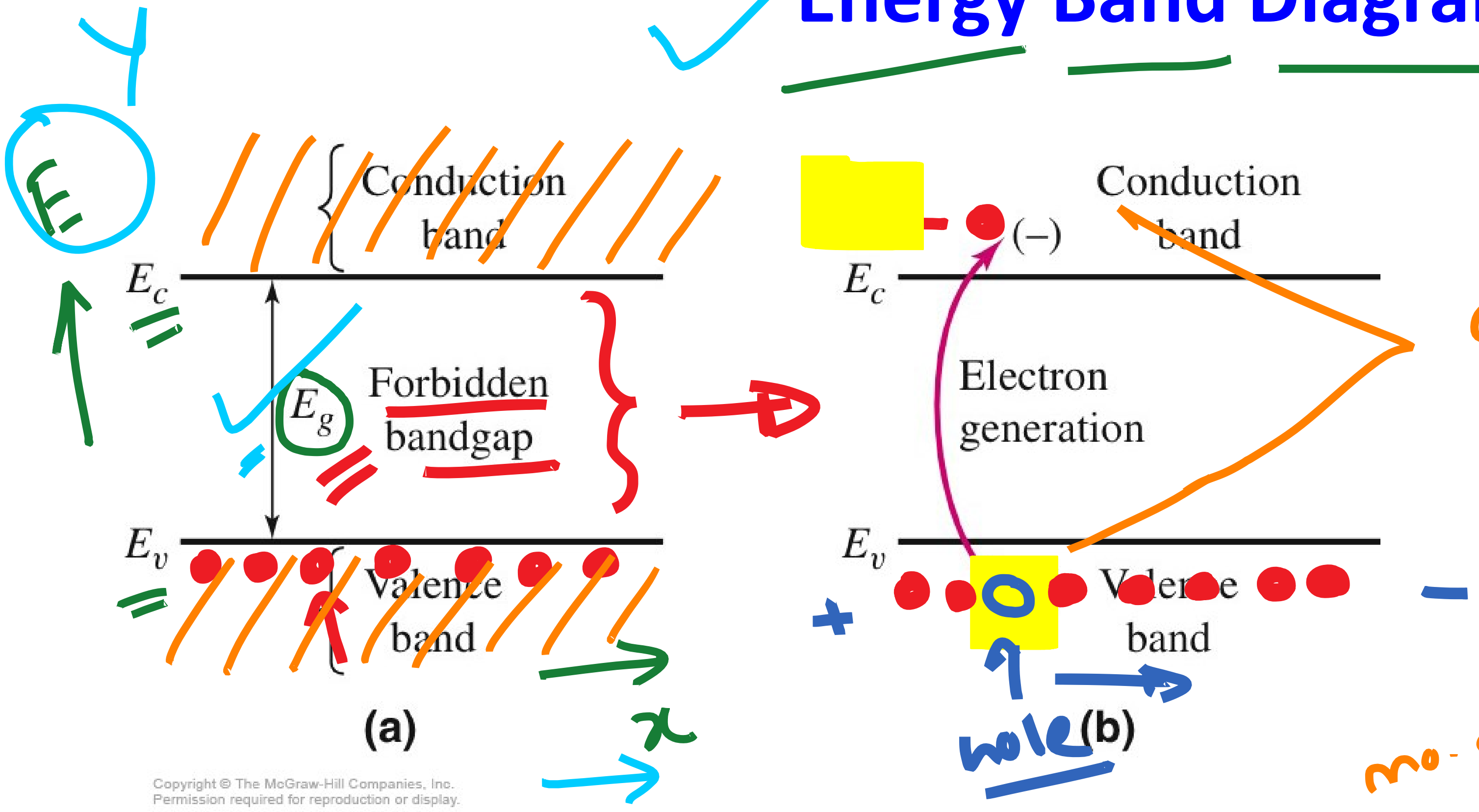
Si is an insulator.

As temperature increases, a bond can break, releasing a valence electron and leaving a broken bond (hole).

Current can flow.

Source: **Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill**

Energy Band Diagram



free electron
↓
hole

generation in pair

no. of electrons = no. of holes

Si, $E_g = 1.1$ ev at 300K

Ge $E_g = 0.66$ ev at 300K

E_v – Maximum energy of valence band

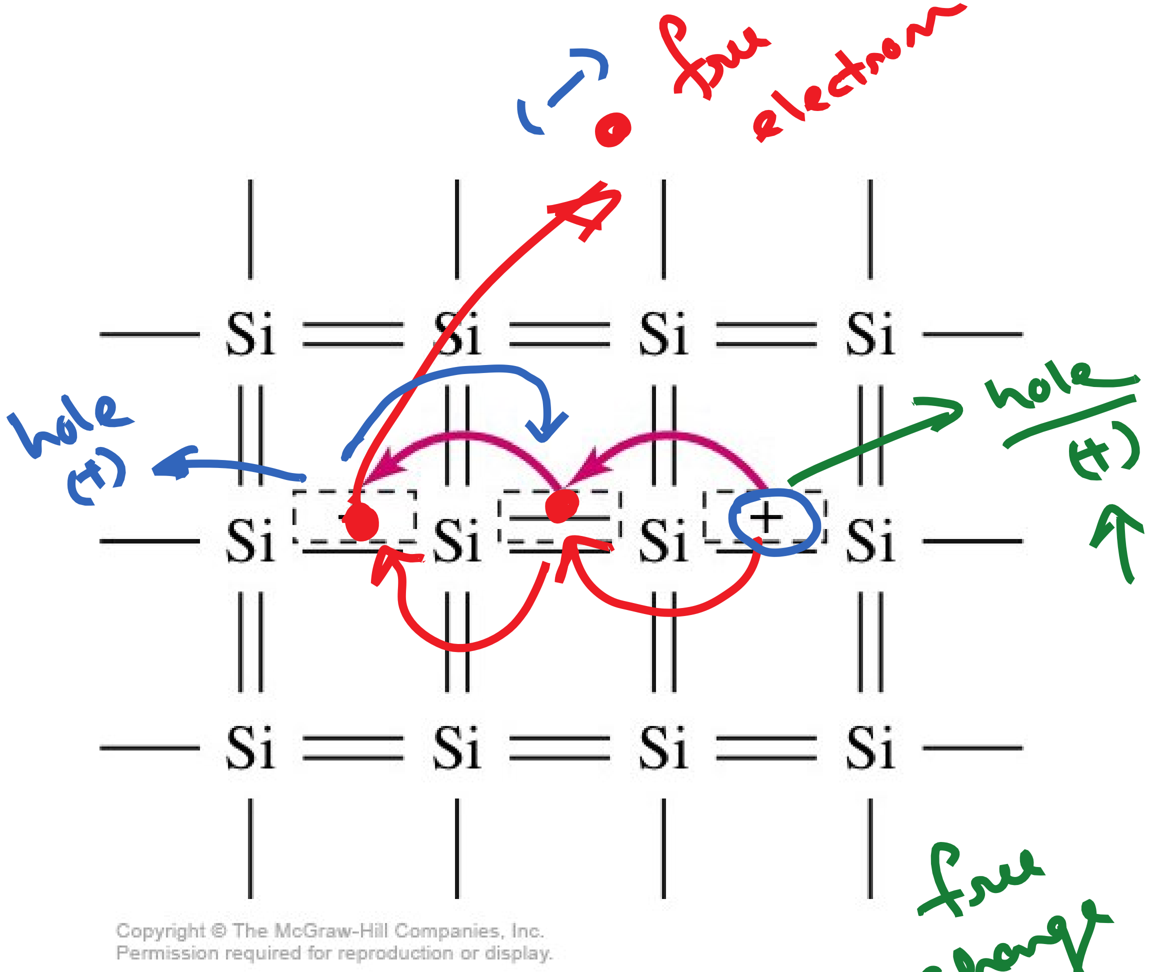
E_c – Minimum energy of conduction band

E_g – Energy required to break the covalent bond → Energy bandgap of a semiconductor

Source: Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill

How does Hole moves??

A valence electron in a nearby bond can move to fill the broken bond, making it appear as if the 'hole' shifted locations.



free charge carrier

Source: Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill

Carrier concentration in pure Silicon

electrons and holes

No impurity → Intrinsic Silicon

Intrinsic carrier concentration (n_i) is given as follows:

$$n_i = B\,T^{3/2} \exp\left(-\frac{E_g}{2kT}\right)$$

B: coefficient, depends on material

T: 300 K

E_g: Bandgap (eV) 1.1 eV

T: Temp (K) = 300 K

k: Boltzmann's Constant. (86×10^{-6} eV/K)

for Si, $B = \dfrac{5.23 \times 10^{15}}{cm^{-3}\,K^{-3/2}}$

T = At 300 K

$n_i = 1.5 \times 10^{10}\ cm^{-3}$ for Si

Conc. of Electron = Conc. of holes $= 1.5 \times 10^{10}\ cm^{-3}$ at 300 K

Conc. of 'Si' atoms $= 5 \times 10^{22}\ cm^{-3}$

Source: Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill

Intrinsic carrier concentration in other semiconductors

$$n_i = B T^{3/2} \exp\left(-\frac{E_g}{2kT}\right)$$

$n_i \approx 2.40 \times 10^{13}$ cm^{-3} at 300K

$n_i \cong 1.8 \times 10^{6}$ cm^{-3} at 300K

* $E_g \uparrow$, $n_i \downarrow$; $T \uparrow$, $n_i \uparrow$

exp exp

Ge

for Ge, $B = 1.66 \times 10^{15}$ $cm^{-3} K^{-3/2}$

$E_g = 0.66\ eV$

Gr-III ← GaAs → Gr-V

$\boxed{III - V}$

→ Compound Semiconductor *

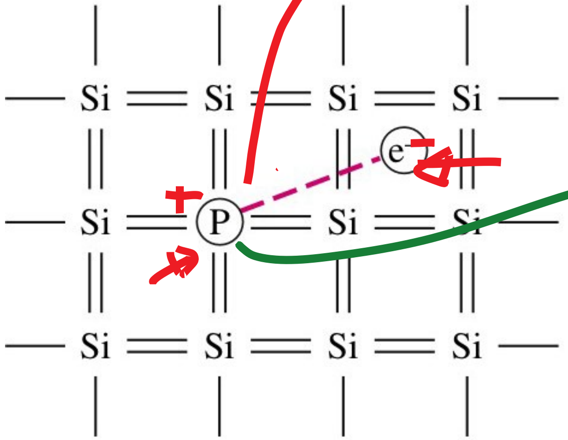
$B = 2.10 \times 10^{14}$ cm^{-3} $K^{-3/2}$

$E_g = 1.4\ eV$

Intrinsic Semiconductor

Source: Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill

Extrinsic semiconductor (Si): when Gr-V impurity is added



(a)

immobile ion

Donar impurity

'P' → 5 valence electrons

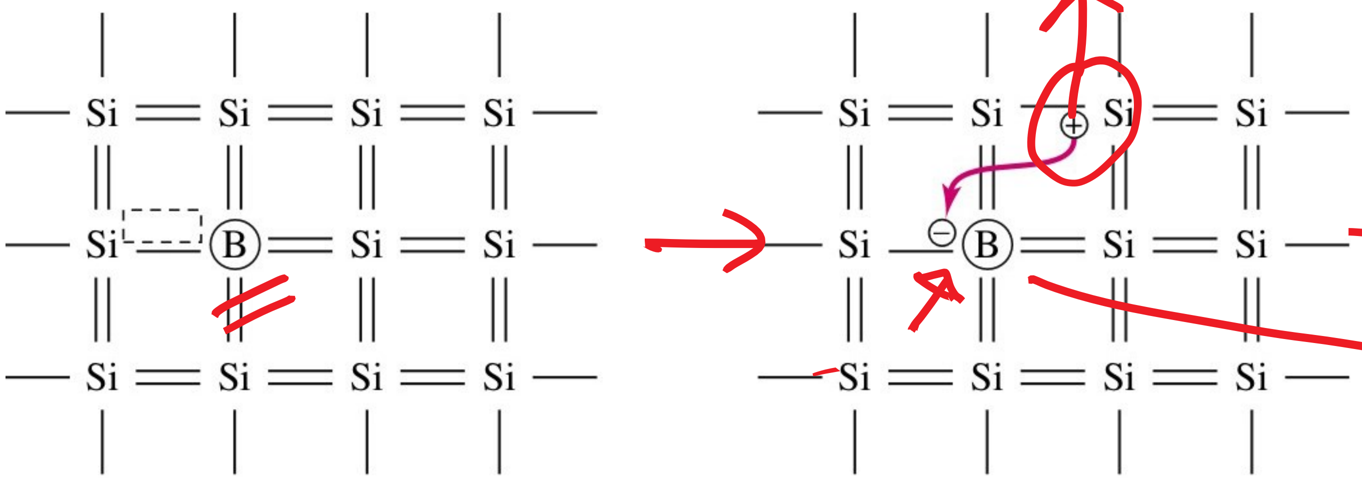
→ n-type Semiconductor

Phosphorous (P) replaces a Silicon atom and forms four covalent bonds with surrounding four Si atoms.

The **fifth** outer shell electron of P is free to become a conduction band electron.

Source: **Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill**

Extrinsic semiconductor (Si): when Gr-III impurity is added



(a) (b)

'B' → '3' valence electrons

'holes' → p-type semiconductor

(−) acceptor impurity

Boron (B) replaces a Si atom and forms only **three** covalent bonds with other Si atoms.

The missing covalent bond is a hole, which can begin to move through the crystal when a valence electron from another Si atom is taken to form the fourth B-Si bond.

Source: **Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill**

Carrier Concentration in Extrinsic Semiconductor

Thermal equilibrium

$$* \quad n_o p_o = n_i^2$$

$p_o \rightarrow$ conc. of holes in Thermal equl.

$n_i \rightarrow$ intrinsic carrier conc.

$n_o \rightarrow$ free electrons in Thermal equl. conc.

n-type Semiconductor:

Donor conc = N_d, $(N_d \gg n_i)$, $n_o = N_d$, $p_o = \dfrac{n_i^2}{N_d}$

p-type Semiconductor:

Acceptor conc. = N_a ; $(N_a \gg n_i)$, $p_o \cong N_a$, $n_o = \dfrac{n_i^2}{N_a}$

Source: Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill

Carrier Concentration in Extrinsic Semiconductor

example

$T = 300K$, Si-bar, P- conc $(N_d) = 10^{16}\ cm^{-3}$, hole conc ??

n-type

n_o

$n_i = 1.5 \times 10^{10}\ cm^{-3}$, at 300 K, $N_d >> n_i$, $n_o p_o = n_i^2$

$n = p = n_i$

$$p_o = \frac{(1.5 \times 10^{10})^2}{10^{16}} = 2.25 \times 10^{4}\ cm^{-3}$$

p-type

N_a

$n_o << n_i$

Source: Electronic circuits: Analysis and Design –by D. A. Neamen, McGraw-Hill